THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

INVESTIGATION OF A DEVICE FOR EVALUATING THE CRACKING OF LINERBOARD

Project 1108-29

Report One

A Preliminary Report

to

TECHNICAL COMMITTEE OF THE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

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INTRODUCTION

A recurrent problem in the manufacture and use of corrugated boxes is rupture or "cracking" of the double-face liner along the score when the board is folded. It is usually a seasonal problem with most difficulties being encountered during winter when inside humidities drop to low levels. Cracking is usually most severe for vertical scorelines where the score is oriented at 90° to the machine direction of the liner—because the strains set up during folding coincide with direction of least stretch. With such considerations in mind, the Institute was requested to undertake an investigation into (a) the nature and magnitude of the strains imposed in the double-face liner when folded, and (b) to evaluate methods for determining the "cracking" potential of linerboard

As one phase, a study of the relationship of various physical characteristics of the liner to its cracking performance in the form of combined board was initiated. Particular attention has been focussed on a "foldability" tester designed at the Institute. The preliminary results are summarized herein.

MATERIALS

Twenty-three samples of linerboard were selected for the study as shown below.

Nominal Weight, lb./M sq. ft.	No. of Samples
42	6
69	8
90	9

DOUBLE-FACING

Double-faced board was produced by hand gluing sheets of the liner-board to a "standard" single-faced board corrugated in the Institute's experimental corrugator. The single-faced board was made with a 42-lb. single-face liner and 26-lb. corrugating medium. The double-facing conditions are noted below:

1. Adhesive: silicate of soda
2. Glue roll clearance in roll coater. approximately 0.008 inch
3. Time under pressure: three minutes at 2 p.s.i. After removal from the press, the board was heated for ten minutes in a 100 to 105°C. oven.
4. Conditioning: after removal from the oven, the combined board was conditioned for at least 48 hours at 50% R.H. prior to scoring.

SCORING

The following conditions were used in scoring the combined board.

1. Score type. "V" male vs. flat female
2. Clearance. sum of liner and medium calipers plus 0.005 inch
3. Scoring dimensions. three 11-inch long scores were inserted in each 18-inch long sheet. The outer scores were three inches from the ends of the sheet, the third score was located in the middle of the sheet
4. Scoring equipment Langston slitter-scorer. A special guide was made to assist in keeping the scores parallel to the flutes.

FOLDING

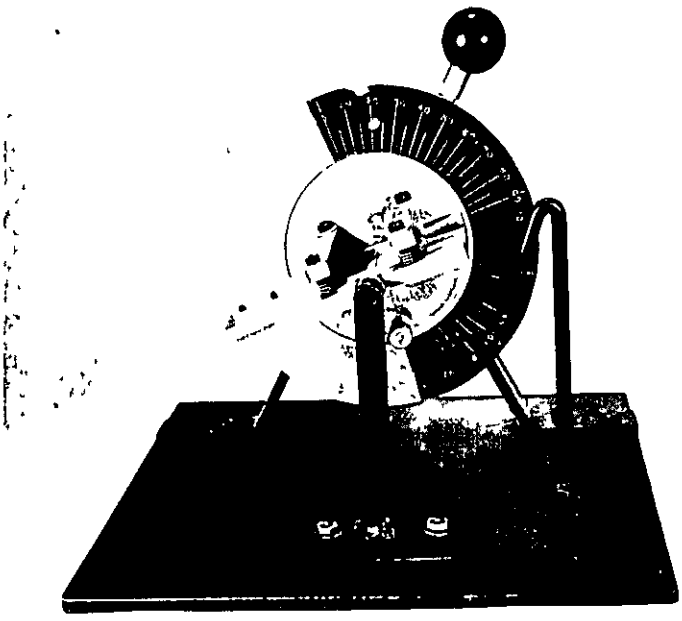
After scoring, the sheets were conditioned for at least 24 hours in the test atmosphere and folded. The folded board was taped together to standardize the handling and viewing conditions and the degree of cracking was evaluated by measuring the extent of the ruptures.

In one phase, a spray coating of flat black paint was applied to the score area by holding the container about 12 to 15 inches from the corrugated board. The purpose of the coating was to increase crack visibility and facilitate measurement of the cracking.

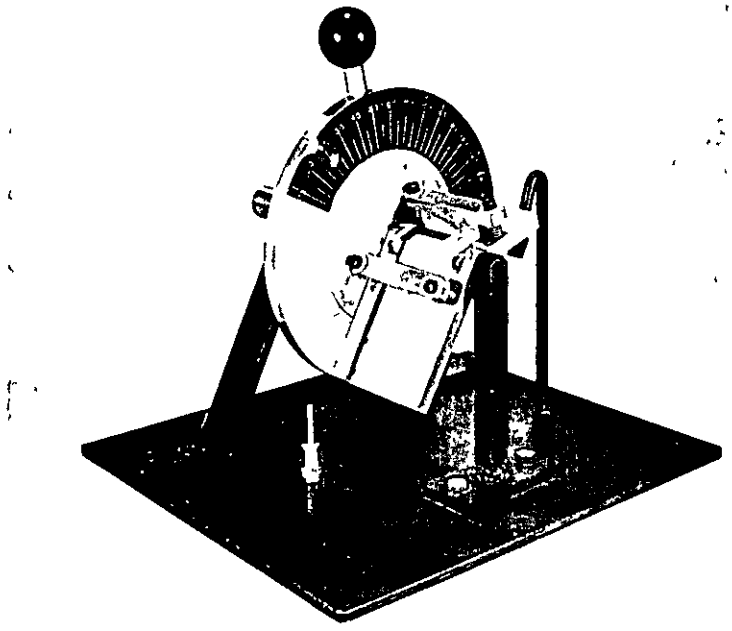
LINERBOARD EVALUATION

Each sample of linerboard was evaluated for weight, caliper, stretch and tensile. In addition, a special device was constructed to evaluate the cracking potential of linerboard. It is shown in Fig. 1. Essentially, the apparatus permits bending a specimen about a solid anvil. When the rupture occurs, a reading of the angle is obtained. It is in an early stage of development and various changes may be made to improve its correlation with combined board cracking and/or simplify its operation.

As used herein, five tests were made on each sample at each of two humidities—20 and 50% R.H.



Movable Specimen Holder Locked in Initial Clamping Position



Specimen Clamp Rotated During Test

Figure 1. Linerboard Cracking Tester

DISCUSSION OF RESULTS

The initial results obtained are tabulated in Table I. As may be noted, combined board fold evaluations were carried out at 0, 10, 20, 30, 40, and 50% R.H. In general, the degree of cracking decreased with increasing relative humidity and decreasing board weight as expected. While a number of reversals occurred it is believed these should be attributed to the subjective nature of the evaluation. This is particularly true when the cracking is not severe.

Correlations between the degree of combined board cracking and the various linerboard characteristics are tabulated in Table II. As may be noted, the correlations were carried out separately for each grade weight as well as on the combined data. In the case of the within grade correlations, the severely limited number of samples should be kept in mind. While the statistical significance of the coefficients has been indicated in the table one additional criterion should be kept in mind, i.e., the sign of the relationship. For example, it is expected that the degree of combined board cracking should decrease as the linerboard cracking angle increases—a negative relationship. Thus, positive correlation coefficients for the linerboard cracking angle test should be treated with reserve. On similar grounds, negative coefficients might be expected with stretch and positive coefficients with caliper and tensile.

With the above in mind, it may be noted

1. For the 90 pound samples, the liner cracking tester tended to be significantly related to combined board cracking—although the presence of two samples exhibiting little or no cracking presumably helped to make the coefficient significant.

TABLE I

RELATIONSHIP BETWEEN COMBINED BOARD CRACKING, RELATIVE HUMIDITY AND LINERBOARD PROPERTIES
(Uncoated samples)

Sample No	Combined Board Degree of Cracking, % Relative Humidity, % 0[c]	10	20	30	40	50	Liner Cracking Angle, ° Relative Humidity 20%	50%	Basis Weight, lb./M sq ft	Caliper, pt	Tensile, lb /in In	Cross	Stretch, % In	Cross
	90-lb Double Face Liners													
2414	100 0	90.1	81 3	86.8	11 5	21 1	62.2	86.0	88.4	25.4	131 2	71.4	1.3	2.6
2420	83 5	40 2	72 0	7.4	1 8	10.0	71.0	113.8	93.5	25.4	145.4	74.1	1.4	3 6
2427	60 6	45.1	47.4	25.3	0 3	1 8	66 0	110.2	92.2	23.5	136.8	74 5	1.8	3 0
2451	28.3	11.3	8.1	34.7	2 8	4 3	64 0	123.0	87.9	26.1	105.4	62 6	1.3	2 8
2464	--[a]	95.0	66 3	5.8	6.6	0 0	85.4	107.4	84.0	24.6	167.4	78.0	2.0	5.1
2465	92.7	75.7[a]	65.7	8 0	2.5[a]	23.2[a]	64.6	111.4	93.6	27.6	149 4	68.6	1.5	3.0
2466	0 0	--[a]	0.0	0.0	--[a]	--[a]	92.0	141.2	90.1	26.7	131.2	87.8	2.0	4.1
2486	0.4	--[a]	0.0	0.0	--[a]	--[a]	110.8	145.0+[b]	93.8	26 2	146 3	87.2	2 0	4.0
2491	53.3	26.5	38.0	5.8	0.3	0.9	75 4	125.2	91.6	25.6	127.6	65.3	1 6	3.0
	69-lb Double Face Liners													
2413	54.6	27.5	3.4	1.0	0.8	2.7	90.4	123.8	70.4	20.0	114.2	55.3	1.5	3.5
2419	44.2	37.8	5.3	3.0	1 8	4 2	84.0	119.8	69.3	20.0	130 6	55.6	1 8	4 8
2422	88 1	61.7	38.2	16.8	3 4	2.0	90.2	132.0	69.4	19 6	113 1	55 6	1 3	2.0
2426	47.3	23.5	3.5	1.4	0.7	0.0	105.1	120.2	72.4	19 9	126 4	62.2	1.9	3.3
2446	77.0	74.8	22.5	12 9	6.3	15.0	97.2	125.6	73.7	20.2	116 2	60.9	1.7	3.3
2459	84.7	29 8	17.7	15.5[a]	1.8	3.1[a]	88 2	129 0	69 5	21.8	118.0	55.2	1.8	3.8
2463	57 8	12 2	1.6	--[a]	1.0	--[a]	82.2	125 8	69 6	22.5	124 7	58.6	1.8	4.3
2489	89 7	60.4	68.5	5 9	1.0	5.0	86.2	126 8	73 0	20.9	130.0	59.0	1.6	3 0
	42-lb. Double Face Liners													
2410	71 2	5 8	0 5	1 4	0 2	0 3	101.8	127.2	42 8	13.4	79 9	34.3	1.6	4.3
2418	29 0	4.0	0 5	0 0	0.0	0.0	103 4	122.6	44 9	12.0	95 5	36.8	1.6	3 9
2421	49 7	19 0	0.7	3 0	0.4	0 4[a]	94.0	123.6	42 7	12.6	86 7	37 2	1.8	3 8
2424	8.7	1.1	0.0	0 9	0 3	--[a]	97.8	128 6	44.0	10.4	84.2	42.2	2 0	4 6
2436	47.9	14.5	1 4	1.4	0.2	0.0	96 0	126.4	43.0	12.1	88 6	37 0	2 1	3 7
2476	28 8	5.3	0.1	0.5	0.0	0.0	96 0	131.2	42.8	12.8	85 9	41.4	1.8	3.0

[a] Specimens not evaluated in view of results obtained at other conditions.

[b] One or more specimens did not crack at maximum angle permitted by tester.

[c] Corresponds to 16 hours oven drying.

Note. Weight, caliper, tensile and stretch were determined at 50% R H.

TABLE II

CORRELATION OF LINERBOARD PROPERTIES WITH COMBINED BOARD CRACKING
(Uncoated samples)

Test	Correlation Coefficient Combined Board Cracking 0% R.H.	10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.	0+10% (Composite)	0+10+20% (Composite)
90-lb. Liner Samples (N=9)								
Liner cracking angle–20% R.H.	-0.63[a]	-0.48	-0.60[a]	-0.57[b]	-0.38	-0.60	-0.57[a]	-0.58[a]
" " " –50% R.H.	-0.90[a]	-0.88[a]	-0.89[a]	-0.73[b]	-0.81[a]	-0.65	-0.90[a]	-0.91[a]
Caliper	-0.27	-0.25	-0.30	-0.22	-0.15	0.38	-0.27	-0.27
Tensile, in	0.44	0.53	0.45	-0.38	0.12	0.04[b]	0.49	0.48
Stretch, in	-0.42	-0.23	-0.42	-0.61	-0.39	-0.67[b]	-0.33	-0.37
69-lb. Liner Samples (N=8)								
Liner cracking angle–20% R.H.	-0.14[a]	0.15	-0.15	0.07[b]	0.24	0.18	0.02	-0.05
" " " –50% R.H.	0.88[a]	0.39	0.55	0.76[b]	0.31	0.05	0.68	0.65
Caliper	0.15	-0.46	-0.07	-0.11	-0.28	-0.21	-0 20	-0.16
Tensile, in	-0.36	-0.23	0.09	-0.57	-0.47	-0.21	-0.33	-0.17
Stretch, in	-0.51	-0.50	-0.48	-0.41	-0.23	-0.05	-0.56	-0.55
42-lb. Liner Samples (N=6)								
Liner cracking angle–20% R.H.	0.09	-0.63	-0 19	-0.62	-0.50	-0.17	-0.10	-0.10
" " " –50% R.H.	-0.24[b]	-0.42	-0.45	-0.26	-0.20	-0.35	-0.31	-0.32
Caliper	0.83[b]	0.36	0.25	0.25	-0.22	0.54	0.79	0.79
Tensile, in	-0.37	0.06	0.25	-0.38	-0.44	-0.44	-0.29	-0.28
Stretch, in	-0.35	0.25	0.33	0.19	0.38	-0.38	-0.23	-0.22
Combined Data (N=23)								
Liner cracking angle–20% R.H.	-0.46[b]	-0.49[b]	-0.67[a]	-0.61[a]	-0.42[b]	-0.57[a]	-0.50[b]	-0.58[a]
" " " –50% R.H.	-0.63[a]	-0.68[a]	-0.68[a]	-0.69[a]	-0.70[a]	-0.60[b]	-0.68[a]	-0.71[a]
Caliper	0.25	0.42[b]	0.54[a]	0.35	0.36	0.42[b]	0.35[b]	0.43[b]
Tensile, in	0.36[b]	0.58[a]	0.64[b]	0.16[a]	0.36	0.35[a]	0.49[b]	0.56[a]
Stretch, in	-0.47[b]	-0.35	-0.46[b]	-0.53[a]	-0.39	-0.53[a]	-0.43[b]	-0.46[b]

[a] Significant at 01 level.

[b] Significant at 05 level.

2. In the other grade weights, none of the linerboard tests appeared to be significantly related to combined board cracking although the limited number of samples in each group and resulting property range should be kept in mind.
3. For the combined data, both liner cracking angle and stretch appeared to be best related to combined board cracking.

In general, the above results suggested that the new test might have promise, however it was not clear whether the relatively poor relationships should be attributed to (a) variability in the subjective evaluations of the cracking in the combined board and linerboard tests, or (b) whether design changes were needed in the linerboard tester itself. To investigate the first alternative, it was proposed to repeat the work applying a black paint coating to the scored areas of the combined board and to the test areas of the linerboard cracking angle specimens. The purpose of the coating was to provide a black background against which cracks would be more visible, thus improving the measurements.

The results obtained on the coated samples are summarized in Table III and the linear correlation coefficients are shown in Table IV in the first four columns The last column in Table IV gives the correlation between the logarithm of the combined board cracking at 20% R.H. and the various test properties. In the table it may be noted that the linear correlations are similar in many respects to those obtained with the uncoated samples. Improvements in correlation seemed to be obtained with the 0% R.H. combined board samples with 90 pound liners, however, this may be due, in part, to the presence of the two low cracking samples (2466 and 2486) in this group. To illustrate

TABLE III

COMPARISON OF COMBINED BOARD AND LINER CRACKING RESULTS
(Black coated fold area)

Sample No.	Combined Board Cracking, % Relative Humidity, % 0	20	30	50	Liner Cracking Angle, ° Relative Humidity, % 20[a]	50[a]
			90-lb. Liners			
2414	100.0	92.1	87.4	47.5	51.6(35.2)	66.8(45.6)
2420	99.6	40.8	40.7	6.4	51.8(36.2)	74.2(52.4)
2427	96.9	22.6	17.8	1.9	62.4(45.4)	78.0(58.0)
2451	92.7	9.9	5.3	0.8	64.4(46.4)	73.2(53.8)
2464	100.0	94.3	83.9	35.8	56.0(38.4)	72.4(51.4)
2465	100.0	59.6	55.8	24.4	52.6(38.6)	73.2(50.0)
2466	42.1	0.1	0.0	0.0	86.4(67.6)	131.6(109.6)[b]
2486	33.8	0.0	0.0	0.0	97.4(77.8)	135.0(120.4)[b]
2491	95.5	25.1	12.8	4.8	64.8(45.4)	84.4(61.0)
			69-lb. Liners			
2413	91.3	25.7	3.6	1.4	72.0(46.0)	77.8(55.2)
2419	80.0	25.5	2.2	0.7	64.0(45.6)	72.8(52.4)
2422	94.3	61.7	13.2	5.6	66.0(45.8)	73.6(53.0)
2426	95.4	15.6	2.4	0.0	62.0(46.4)	68.2(52.8)
2446	95.6	67.2	15.6	13.0	63.0(43.4)	82.2(58.2)
2459	94.9	65.7	5.1	1.8	67.8(46.4)	81.8(57.6)
2463	98.9	46.4	3.3	3.2	59.4(42.4)	77.0(54.4)
2489	98.0	79.6	21.4	14.9	59.2(39.4)	85.4(62.0)
			42-lb. Liners			
2410	73.2	16.2	1.4	0.1	69.6(50.6)	82.4(69.0)
2418	68.2	1.8	0.7	0.1	74.8(54.0)	79.6(64.4)
2421	62.0	9.4	1.2	0.8	72.0(50.0)	86.6(63.2)
2424	75.6	13.0	1.0	0.2	80.2(56.6)	94.8(77.6)
2436	86.0	27.1	3.1	1.6	75.0(52.8)	80.6(62.6)
2476	80.9	4.4	1.5	0.1	78.6(51.4)	86.2(65.0)

[a]The first figure is the angle at which an open crack was observed. The figure in parentheses is the angle at which the first minor crack in the coating was observed.

[b]One or more specimens did not crack at the maximum angle permitted by the tester.

TABLE IV

CORRELATION OF LINER PROPERTIES WITH COMBINED BOARD CRACKING
(Black coated samples)

Test	Correlation Coefficient Combined Board Cracking 0% R.H.	20% R.H.	30% R.H.	50% R.H.	Logarithm (20% R.H.)
90-lb. Liner Samples (N=9)					
Liner cracking angle–20% R.H.					
First coating crack (FCC)	-0.97[a]	-0.74[b]	-0.72[b]	-0.60	-0.97[a]
Open crack (OC)	-0.96[a]	-0.74[b]	-0.73[b]	-0.60	-0.97[a]
Liner cracking angle–50% R.H.					
First coating crack (FCC)	-0.99[a]	-0.68[b]	-0.65	-0.54	-0.98[a]
Open crack (OC)	-0.99[a]	-0.68[b]	-0.65	-0.54	-0.97[a]
Caliper	-0.36	-0.20	-0.17	-0.06	-0.35
Tensile, in	0.03	0.51	0.53	0.40	0.17
Stretch, in	-0.63	-0.25	-0.25	-0.24	-0.58
69-lb. Liner Samples (N=8)					
Liner cracking angle–20% R.H.					
FCC	-0.45	-0.59	-0.69	-0.80[b]	-0.56
OC	-0.35	-0.25	-0.34	-0.44	-0.19
Liner cracking angle–50% R.H.					
FCC	0.48	0.77[b]	0.74[b]	0.80[b]	0.69[b]
OC	0.38	0.81[b]	0.65	0.72[b]	0.81[b]
Caliper	0.45	0.33	-0.12	0.00	0.38
Tensile, in	-0.22	-0.18	-0.06	0.02	-0.25
Stretch, in	-0.07	-0.34	-0.48	-0.30	-0.38
42-lb. Liner Samples (N=6)					
Liner cracking angle–20% R.H.					
FCC	0.24	0.00	-0.18	-0.14	-0.08
OC	0.44	-0.19	-0.06	-0.14	-0.19
Liner cracking angle–50% R.H.					
FCC	0.04	0.02	-0.39	-0.46	0.20
OC	-0.06	-0.10	-0.33	-0.27	0.19
Caliper	-0.10	-0.04	0.15	-0.03	-0.03
Tensile, in	-0.15	-0.36	-0.09	0.15	-0.64
Stretch, in	0.59	0.64	0.65	0.69	0.61
Combined Data (N=23)					
Liner cracking angle–20% R.H.					
FCC	-0.92[a]	-0.70[a]	-0.59[a]	-0.55[a]	-0.91[a]
OC	-0.88[a]	-0.70[a]	-0.65[a]	-0.59[a]	-0.84[a]
Liner cracking angle–50% R.H.					
FCC	-0.90[a]	-0.53[a]	-0.41	-0.37	-0.89[a]
OC	-0.86[a]	-0.46[b]	-0.38[b]	-0.34	-0.85[a]
Caliper	0.20	0.35[b]	0.47[b]	0.40[b]	0.01
Tensile, in	0.23[b]	0.48[b]	0.61[a]	0.51[b]	0.10
Stretch, in	-0.45[b]	-0.29	-0.30	-0.28	-0.39

[a] Significant at .01 level [b] Significant at .05 level

the above, the 0 and 20% R.H. combined board cracking results are plotted against the liner cracking angle in Fig. 2. It is apparent that the regression line will be quite dependent upon the position of the two isolated points at the right for the 0% combined board results. The 20% R.H. combined board results plotted on the right suggest that a nonlinear relationship would give a better fit to the 20% R.H. combined board data than the straight line shown in the figure. For example, in Table IV fitting an exponential function to the data raised the correlations considerably.

In any event, nonlinear correlations of the data may be helpful and this avenue will be explored as time permits.

In general, it appears that the linerboard cracking device may have promise for mill quality evaluation; however, further improvements in design appear necessary to improve its correlation with field performance.

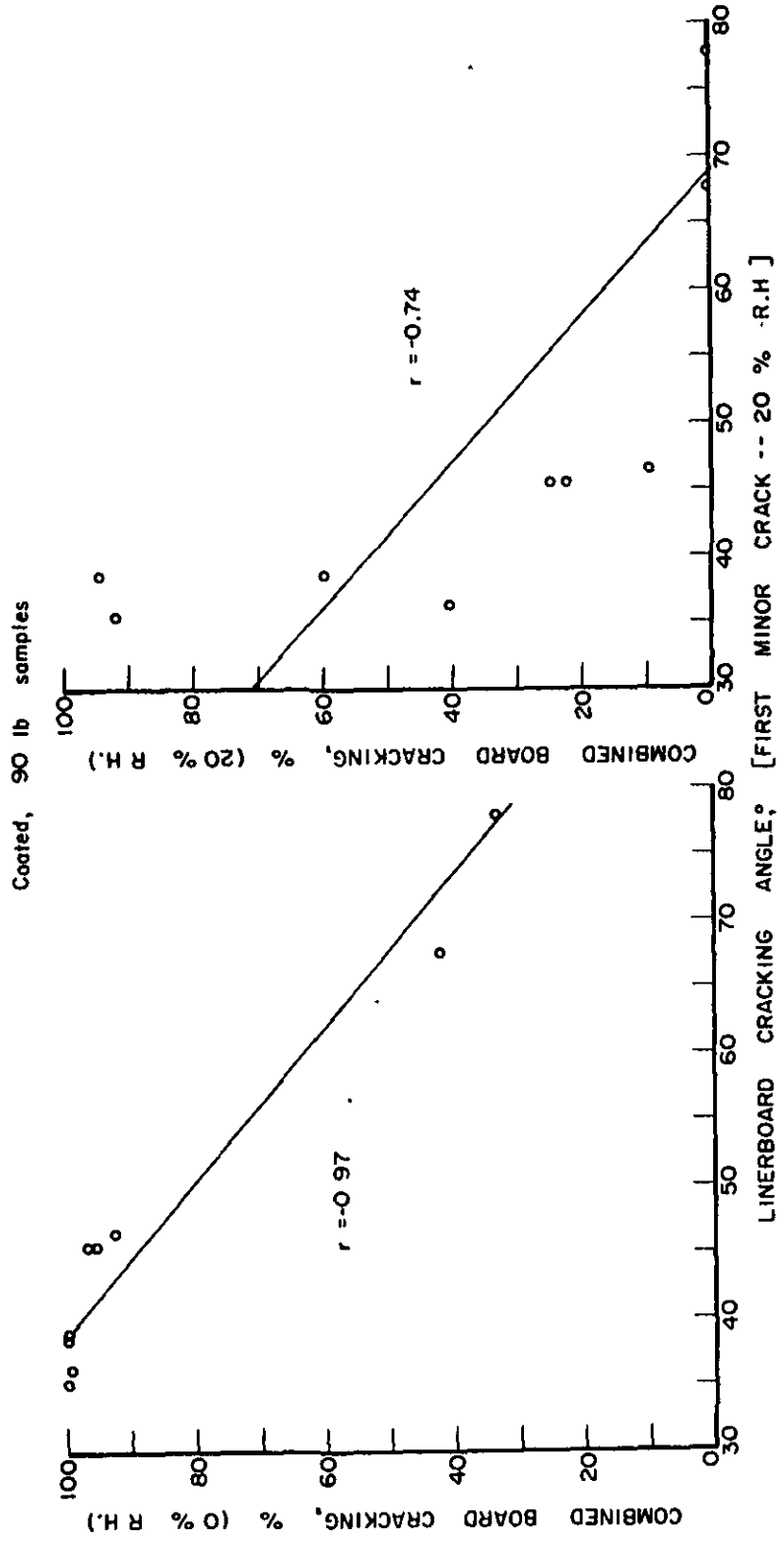


Figure 2. Relationship Between Combined Board Cracking and Liner Cracking Angle